

OFFSHORE TESTING OF BOOMS AND SKIMMERS

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INTRODUCTION

These offshore trials of oil spill containment and recovery equipment came about in order to meet several needs identified by various agencies. Foremost was the desire to find out whether or not offshore containment and recovery equipment presently stockpiled by the Canadian Coast Guard was suitable for use on spills of oils typical of the waxy crude oils discovered on the Grand Banks. These oils exhibit atypical spill behaviour (S.L. Ross and DMER 1987) and may not be amenable to recovery with conventional oleophilic or weir-type skimmers (S.L. Ross and Hatfield 1986). As well, the operating characteristics of the RO-BOOM and Vikoma Ocean Pack boom were to be compared to determine whether or not one best suited the needs of Coast Guard. In addition there was a desire to field test a novel skimmer developed for the Coast Guard for heavy, viscous oils (Canpolar 1986) on waxy crude oil. Coincidentally, the Oil and Hazardous Materials Environmental Test Tank (OHMSETT) Interagency Technical Committee (OITC) had a need to verify at sea, with oil, a boom testing protocol intended to correlate a boom's ability to contain oil with its seakeeping ability. If successful this protocol would preclude the need for most offshore testing of booms with oil. Trials with a specially instrumented boom had been conducted in the OHMSETT tank with oil and offshore without oil; these trials were to be the final component of the test program: tests offshore with and without oil.

Objectives

The objectives of the offshore trials were to document and quantify:

- * the sea-keeping and waxy oil containment capabilities of the Vikoma Ocean Pack and RO-BOOM in seas representative of Grand Banks conditions;
- * the waxy oil recovery capabilities of the Framo ACW-400 type skimmer and the experimental Heavy Oil Skimmer; and
- * the sea-keeping and oil retention capabilities of a specially instrumented offshore oil boom in seas representative of offshore conditions.

This paper documents the methodology, results, conclusions and recommendations arising from the study pertaining to the first two objectives noted above. A separate paper is being written on the final objective of the study by OHMSETT staff (McKowan and Borst 1987).

Test Site Selection

The proposed test area was selected in consultation with the Regional Ocean Dumping Advisory Committee (RODAC) based on the following criteria:

- * any minor oil losses must drift out to sea (SSW currents and westerly winds)
- * at least 100 m water depth

- * at least 20 nm offshore
- * within 2 to 3 hours sailing from St. John's

The site chosen was an area (Figure 1) centred at 47° 40'N, 52° 03'W east of St. John's. An area, rather than a specific site was selected to permit flexibility in test selection on the day of the trials and to account for "over the ground" drift during the trials.

The site and the possible time window for the trials (September 1 to October 31, 1987) were specifically chosen to avoid conducting the trials during the fishing season and to optimize the chances of suitable sea and weather conditions.

EQUIPMENT AND METHODS

The Oil

Due to the unavailability of sufficient quantities of a Grand Banks crude (about 75 m³ was required as the volume necessary to provide realistic contained slick area and thickness) it was necessary to produce an oil with properties similar to those typical of Grand Banks' crudes (Table 1).

TABLE 1
COMPARISON OF OIL PROPERTIES

OIL	API GRAVITY	DENSITY @ 15°C (KG/M ³)	VISCOSITY (mPas)	POUR POINT (°C)
HIBERNIA	36	844	11 @ 15°C	6
AVALON	29	877	93 @ 15°C	10
TERRA NOVA				
DST-1	31	871	8.7 @ 50°C	27
DST-2	32.9	861	16.7 @ 25°C	12

In order to achieve this, Brent crude, from the North Sea, was modified by the addition of 1% by volume of slack wax (the unprocessed wax precipitate from crude oil refining operations) to raise its pour point from 0° to 6°C. Laboratory weathering studies showed that the pour point of this oil as a 10 cm thick slick in a 9 m/s wind at 15°C would increase from 6°C to 15°C in ten hours. Since there was a desire to test the OHMSETT instrumented boom (scheduled to be tested first) with a fluid oil, this degree of pour point elevation was judged to be optimum for the expected 10–12°C waters.

The fresh, doped Brent crude had a density of 839.8 kg/m³ and a viscosity of 20 mPas at 12°C.



FIGURE 1 - LOCATION OF SUGGESTED TEST AREA

Environmental Data Gathering

Meteorological Information Wind speed and direction were recorded every 15 minutes during the trials using the anemometer and weathervane mounted on the CCGS Grenfell. These readings were subsequently corrected for the vessel's speed and heading. Water and air temperatures were also determined periodically throughout the day with mercury-in-glass thermometers.

Sea State Although a waverider buoy was deployed at the test site, and had functioned perfectly during the dry run two days previously, no detailed wave data were collected due to receiver failure. Visual estimates of wave height, length and period and swell height, length and period were made intermittently throughout the trial.

Boom Performance

Boom configuration was recorded by aerial and surface video and still photography. Relative boom/surface water velocity was measured by timing the drift of wood chips over a known distance along the side of the boom tow vessels. This data was converted to a relative velocity at the boom pocket by:

$$V = \frac{(U_1 + U_2)}{2} \cos (\theta/2)$$

where V = relative boom/water velocity (m/s)
 U₁, U₂ = measured drift at tow vessels 1 and 2 (m/s)
 θ = angular separation of the two vessels (°)
 = difference in vessel headings at time of drift measurement

The rate of oil leakage from the booms was estimated from aerial video and still photography by determining the width of sheen leaking past the boom and multiplying by the relative boom/water velocity and an assumed slick thickness (10 µm for sheen, 1 mm for dark oil). This technique provides a reasonable relative comparison of boom leakage rates for booms tested under similar conditions; more accurate quantitative data would be available if the aerial photography had been supplemented with surface slick thickness data. This was not deemed necessary by the project steering committee.

General boom performance (wave conformance, ease of deployment, and recovery, durability, manoeuvrability etc.) were monitored throughout the trial and recorded by surface video and still photography.

Skimmer Performance

The deployment, operation and retrieval of the three skimmers was recorded on videotape and still photographs. Observations on general skimmer performance (sea keeping, proximity to thick oil, flow of oil to skimmers, etc.) were made visually by trained personnel.

The recovery performance of each skimmer was measured by OHMSETT staff using the following equipment:

- * a 10 cm (4 inch) Venturi meter with Rosemount pressure gauges and a Telog data recorder was used to monitor fluid flowrates from each skimmer during recovery operations. The output used from the data recorder was a 3 second average flowrate. Twenty consecutive outputs were later averaged to give a one minute average flow. This was necessary to remove the effects of the vessel's roll on the pressures recorded;
- * periodic soundings of the 23 m³ (6000 gallon¹) receiving tanks were made to measure recovered fluid volumes;
- * small samples of recovered fluid were drawn from the skimmer discharge every five minutes during recovery operations and analyzed for density (by weighing a known volume), viscosity (Brookfield viscometer) and water content (by centrifugation followed by volumetric analysis);
- * stratified samples (covering 15 cm = 6 inches of fluid each) of the recovered fluid in the two tanks were taken with a Johnson sampler and analysed for oil, free water and emulsified water content to determine overall oil recovery factors.

3.0 RESULTS AND DISCUSSION

General

Figure 2 shows the sequence of activities on the day of the trials. Due to the need for sea state 3-4 related to the OHMSETT instrumented boom data collection and in view of the forecast wind and wave conditions it was necessary to alter the test protocol and release the oil into the RO-BOOM first, test the RO-BOOM and then release the oil into the OHMSETT instrumented boom.

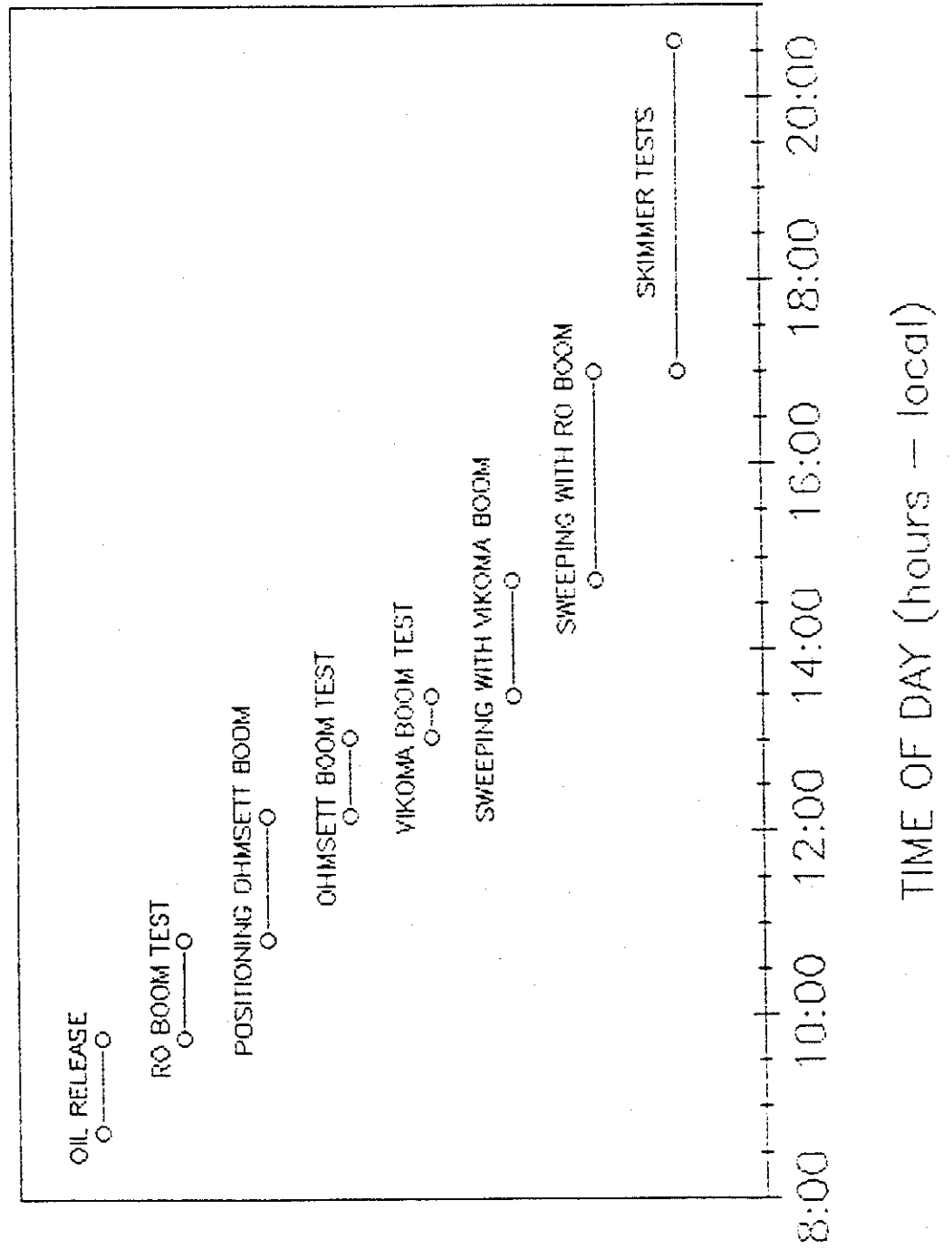
The oil was pumped from the stern of the M/V Terra Nova Sea, commencing at 0846 and finishing at 0944, into the mouth of the RO-BOOM being held by the M/V Triumph Sea and the M/V Beinir (Figure 3). Some 67.7 m³ (17,885 gal) of oil were released in this manner at approximate position 47° 42'N, 52° 47'W. All the oil entered the mouth of the boom catenary.

From 0944 to 1050 the seakeeping and oil containment capabilities of the RO-BOOM were evaluated at relative boom/water velocities of less than 0.4 m/s 0.75 knots (Figure 4). The oil was released from the RO-BOOM by letting go the tow line from the M/V Beinir at 1050; no testing to first loss (i.e., towing at speeds in excess of 0.5 m/s = 1 knot) was conducted with the RO-BOOM.

Difficulties were encountered in holding the OHMSETT instrumented boom in position without the boom twisting. As such, at the time of the oil release from the RO-BOOM, the OHMSETT instrumented boom was approximately 1.5 km downdrift of the thick oil. After about an hour of manoeuvring, a portion of the thick slick was captured by the OHMSETT instrumented boom. During this time the Vikoma boom was deployed in a catenary in the path of the drifting thick oil (Figure 5). Testing of the OHMSETT instrumented boom commenced at 1210 and concluded at 1302.

1. in this report gallons refer to U.S. gallons (1 m³ = 264 U.S. gal)

FIGURE 2
TRIAL TIMETABLE



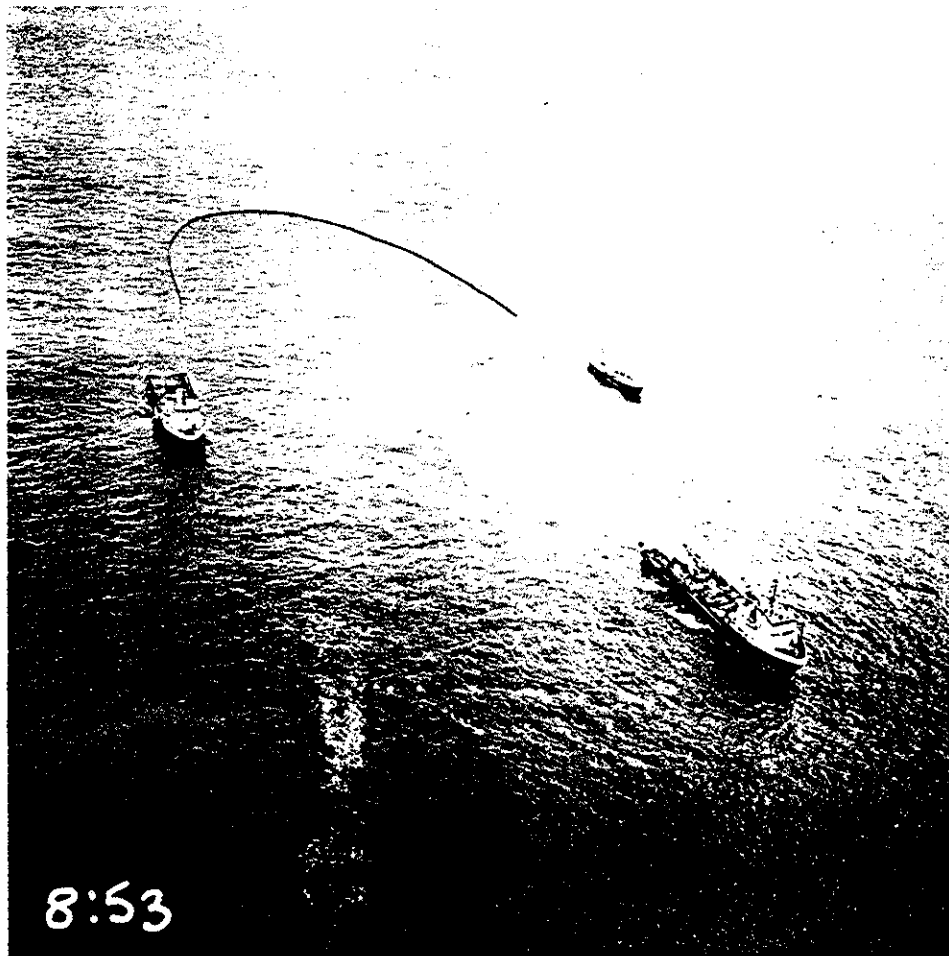


Figure 3 — Oil drifting into RO-BOOM

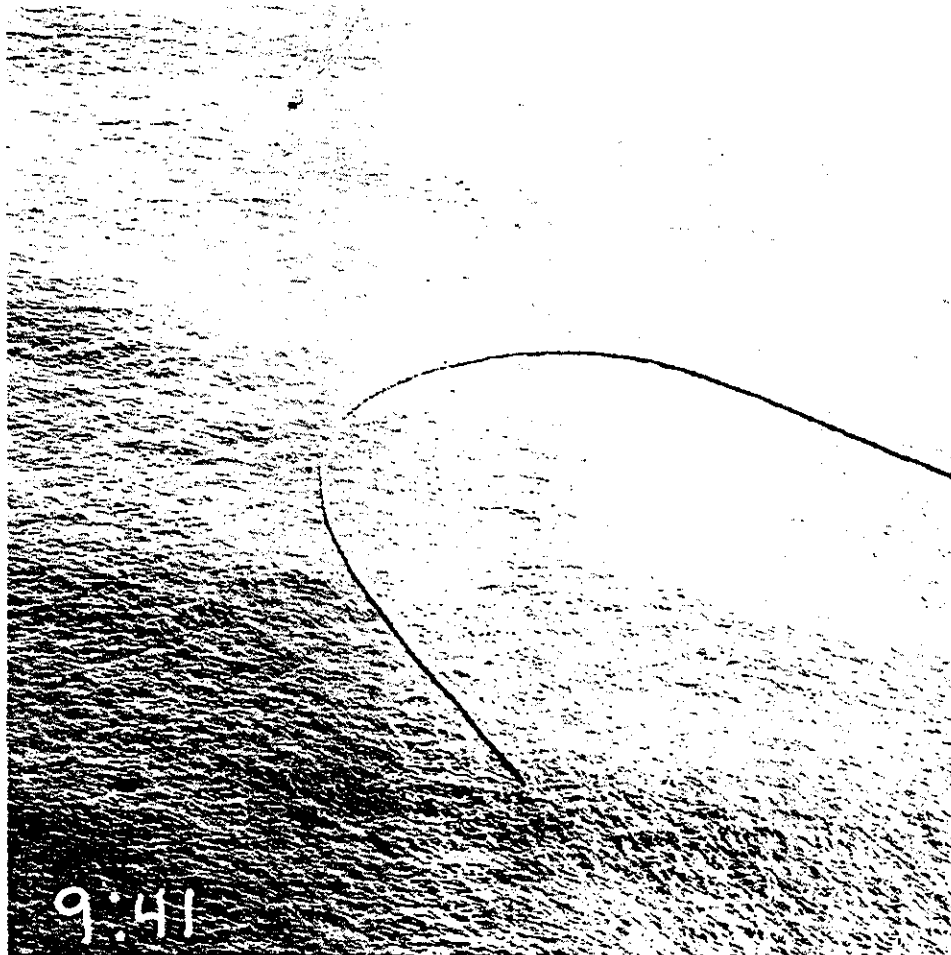


Figure 4 — Testing of RO-BOOM; note thick oil in pocket. Losses are sheen only.

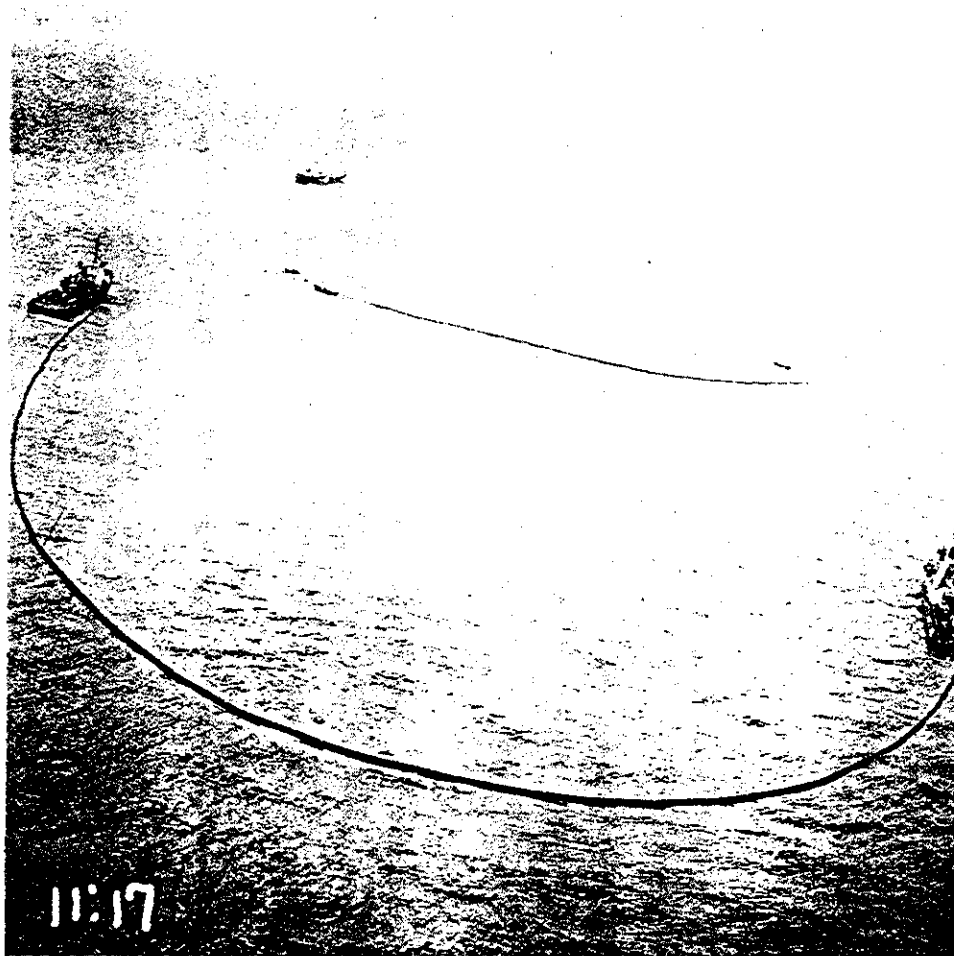


Figure 5 — Vikoma Ocean Pack deployed behind OHMSETT instrumented boom in path of slick

Although the Vikoma boom was positioned across the drift path of the slick, in manoeuvring to intercept the oil released from the OHMSETT instrumented boom at the completion of its test, some of the thick oil not originally contained by the OHMSETT boom drifted past the mouth of the Vikoma boom (Figure 6). This manoeuvring also caused the loss of the small volume of oil already collected. After one half hours testing of the Vikoma boom containing thick oil, the M/V Grenfell (on the starboard) began to slowly move ahead to form a "J" boom configuration for the skimming tests. Unfortunately, because the vessels were heading into a 7–10 m/s (15–19 knot) wind, the Grenfell moving forward caused the relative boom/water velocity to exceed 0.5 m/s (1 knot) and all the oil collected escaped by 1348 (Figure 7). Following this the Vikoma boom was repositioned with the vessels heading downwind and some thick oil was recaptured by the Vikoma boom. Much of this oil was lost under the boom a second time when manoeuvring to form a "J" boom configuration for the skimming tests due to excessive speed. Attempts were made to deploy the Heavy Oil Skimmer at 1445 into what remained of the oil in the Vikoma boom however the boom pocket had collapsed and it proved impossible to insert the skimmer into the oil.

Between 1500 and 1700 the RO-BOOM was used in a "U" configuration oriented downwind to chase down and capture the thick oil slicks. From 1700 to 2036 the skimmer tests were conducted from the skimmer vessel (M/V Terra Nova Sea) stationed broadside to the RO-BOOM pocket (Figure 8).

The skimmers were tested in the following sequence:

- 1) The Heavy Oil Skimmer was deployed; no recovery was observed.
- 2) The Framo ACW-400 skimmer was deployed and operated for 23 minutes. During the last few minutes of this test Elastol was applied to the contained oil.
- 3) The Heavy Oil Skimmer was deployed; problems with the pump precluded recovery operations and one drum was damaged.
- 4) The GT-185 skimmer was deployed and operated for 29 minutes.
- 5) The Heavy Oil Skimmer was redeployed with only one drum fully operational. During this last attempt the discharge hose burst just as the initial measurements of recovery were being made.

The trials ended at 2036 due to the failure of the Heavy Oil Skimmer, darkness and increasing winds forecast for the area.

Environmental Conditions

Winds The wind speed remained relatively constant in the morning at 5 to 6 m/s (10 to 12 knots) and increased in the afternoon to 7 to 9 m/s (14 to 18 knots). Winds in the evening increased further to 9 to 10 m/s (18 to 20 knots). The wind direction remained relative constant from the southwest. Over the following 48 hours the winds shifted from southwesterly to westerly and averaged 4 to 8 m/s (8 to 16 knots), increasing to 8 to 13 m/s (16 to 25 knots) with gusts to 18 m/s (35 knots), 48 hours after the completion of the trials.



Figure 6 — Vikoma Ocean Pack being manoeuvred to intercept oil from OHMSETT instrumented boom.

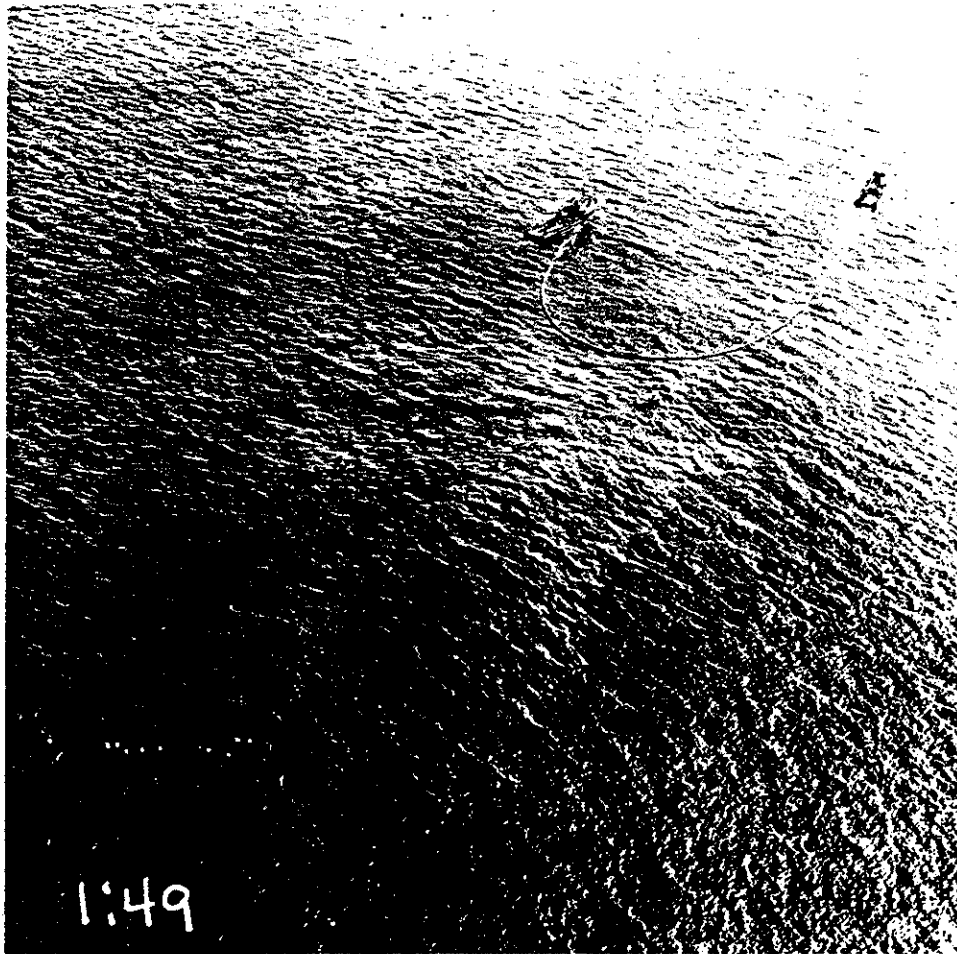


Figure 7 — Oil lost from Vikoma Ocean Pack during manoeuvring boom into "J"

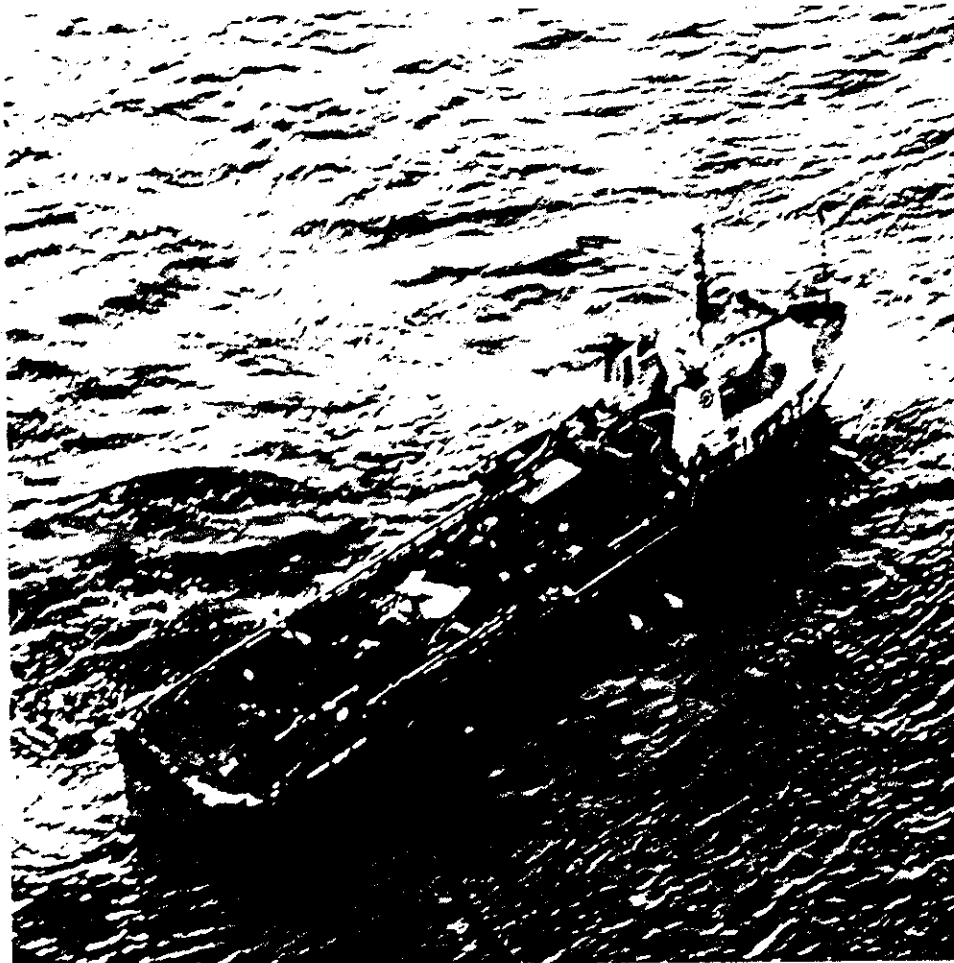


Figure 8 — Skimmer tests being conducted in pocket of RO-BOOM

Sea State At the commencement of the trials the waves averaged 0.5 m (Sea State 2) with a swell of 2.5 m (personnel in small boats reported occasional swells of 4 m). As the day progressed the wave height increased to about 1.3 m (Sea State 3-4) and the swell height decreased to 1.5 to 2.0 m.

Temperature The water temperature remained constant at 12°C throughout the day. Air temperatures increased from 12°C at sunrise to 14°C by sunset.

BOOM PERFORMANCE

This section of the report deals only with the evaluation of the RO-BOOM and Vikoma Ocean Pack. Details of the testing of the OHMSETT instrumented boom (McKowan and Borst 1987) are covered in a separate paper.

Deployment and Recovery

RO-BOOM The deployment of the two 200 m sections of the RO-BOOM required approximately 110 minutes over the gunwale of the CCGS Sir Humphrey Gilbert during the dry run and 105 minutes over the stern of the M/V Triumph Sea during the trials. Deployment over the stern of a supply boat was much easier than over a gunwale.

Recovery of the RO-BOOM over the gunwale took 80 minutes and was very difficult even in the calm conditions prevalent during the dry run. Up to 14 personnel were involved in boom recovery in this instance. Recovery over the stern of a supply boat was much less labour intensive (six personnel) and easier even though it was dark and the winds and seas were much higher than during the dry run. The time required to recover the boom was 100 minutes, slightly longer than during the dry run because the boom was rinsed of oil as it was being recovered.

Vikoma Ocean Pack The deployment of the Vikoma boom was accomplished in approximately 20 minutes during both the dry run and the trial. Recovery onto the hydraulic reel took about 30 minutes each time, however, it was necessary to remove the boom from the reel after each recovery and restow it into the boom box. This required about an hour. Deployment required three personnel; recovery required six, and restowing the boom required eight personnel.

Comparison The deployment and recovery of the Vikoma boom is faster and less labour intensive than that of the RO-BOOM, however, in the context of offshore spill response both booms were judged to be acceptable, providing these operations are conducted from the aft deck of a supply vessel. It should be noted that Roulunds, the manufacturers of the RO-BOOM, are continuing to improve the valving system and hope to reduce deployment times to about 10 minutes per 200 m section.

Manoeuvring and Durability

Both booms proved to be very manoeuvrable and no problems with overturning or twists were noted. No damage to the RO-BOOM was noted after 17 3/4 hrs

deployment including 3 hrs skimming operations; all the floatation chambers were still fully inflated when the boom was recovered.

The Vikoma boom suffered one incident of sinking when excessive strain during manoeuvring caused the band holding the air chamber to the power unit to slip off. This problem was rectified in about one half hour and the boom itself was undamaged.

Overall, the RO-BOOM was judged to be somewhat more durable for long-term offshore deployment because it does not depend on the continuous operation of a power source and the tearing and loss of one or more floatation units should not affect the overall integrity of the boom. Power failures and large tears can cause temporary losses of containment capability for the Vikoma Ocean Pack. Both booms were judged sufficiently manoeuvrable and durable for use offshore.

Sea Keeping and Oil Retention

RO-BOOM Oil was in contact with the RO-BOOM for two time periods during which data on seakeeping and oil retention was collected: first during the oil release and RO-BOOM trials from approximately 0900 to 1050 and second during the skimmer trials from 1700 to 1900 hrs. At all times the RO-BOOM followed the waves and swell very well and maintained its desired configuration.

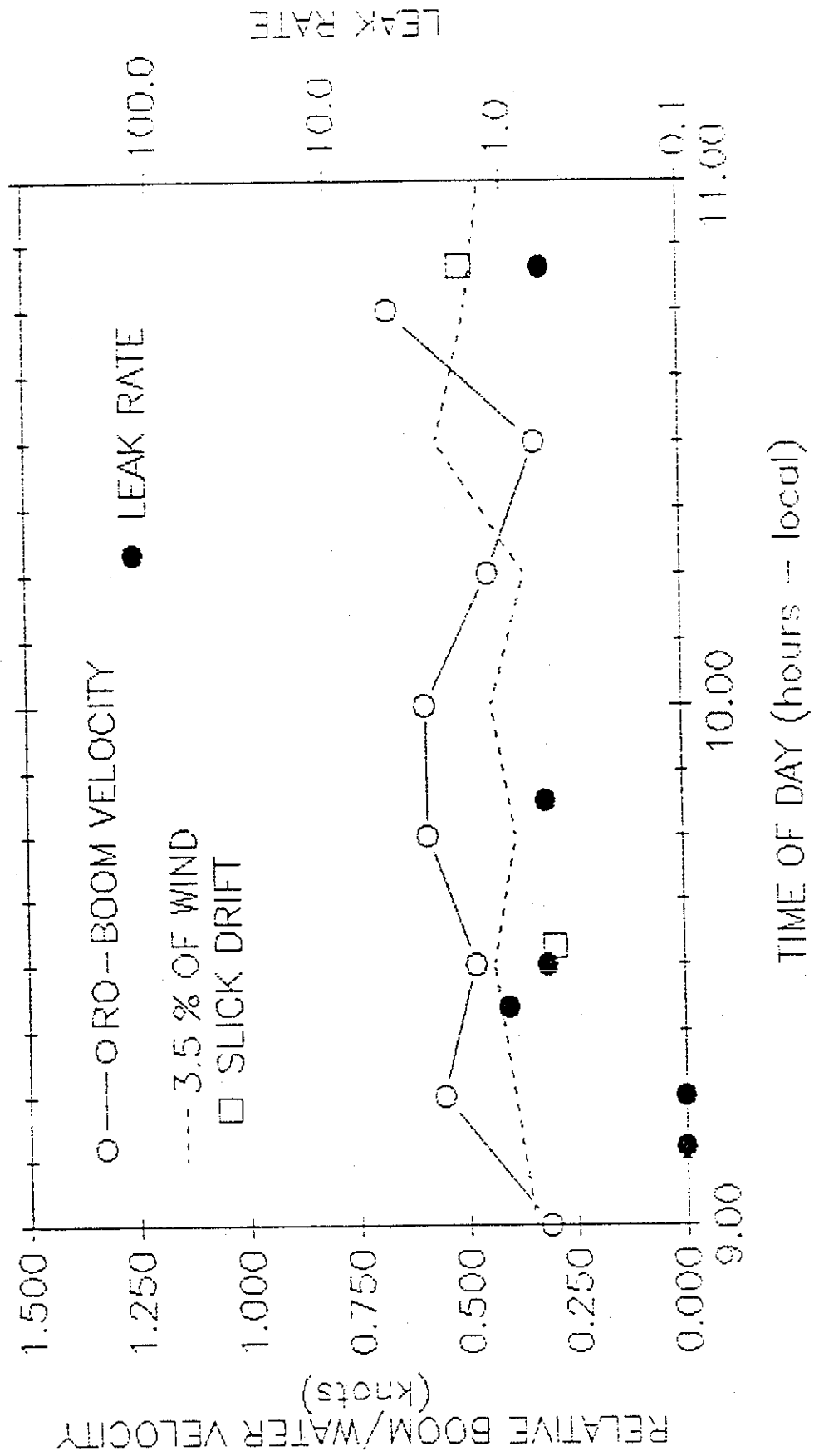
Figure 9 compares the visually estimated oil leakage rate from the RO-BOOM during its morning trials with the calculated relative boom/water velocity. Also shown are the calculated wind-induced surface water velocity and measured (from aerial videotapes) slick drift rate. The three measures of relative water velocity agree reasonably well; the calculated relative boom/water velocity is generally slightly higher than the other two due to the need for the one tow vessel (M/V Beinir) to maintain steerage way.

The estimated relative oil leakage rates are very low initially at approximately 0.1² because only small amounts of oil had reached the boom pocket (Figure 10). By 0930 when most of the oil had reached the boom pocket the leak rate had increased to 0.5 to 1.0 (Figure 11); this leak rate remained reasonably constant throughout the test period (Figure 9). Some splashover of oil at the joints between floatation sections was observed near the end of the test (around 1050) when the winds had increased to 7 m/s (15 knots) and the relative boom/water velocity was calculated to be around 0.3 m/s (0.6 knots). The volumes of oil lost were not considerable.

One thickness measurement in the boom pocket near the end of the test period was reported; it indicated the contained slick to be an estimated 30 cm thick at the boom. Simultaneous aerial video and still photography shows an area of contained oil of some 200 m². Assuming the slick thickness was relatively constant throughout (Wicks 1969; Lau and Kirchhefer 1974; Delvigne 1984), this would translate to a contained volume of approximately 60 m³ or almost all the 67.7 m³ discharged. No additional data was collected to confirm the variation in slick thickness, although the low observed leakage rates would tend to substantiate the conclusion that virtually all the oil released into the RO-BOOM was contained for the duration of its test and

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2. the procedure used to arrive at this number results in units of L/s, however without actual slick thickness data to work with the numbers can only be used for relative comparison and are reported without units.

FIGURE 9
RO-BOOM LEAKAGE



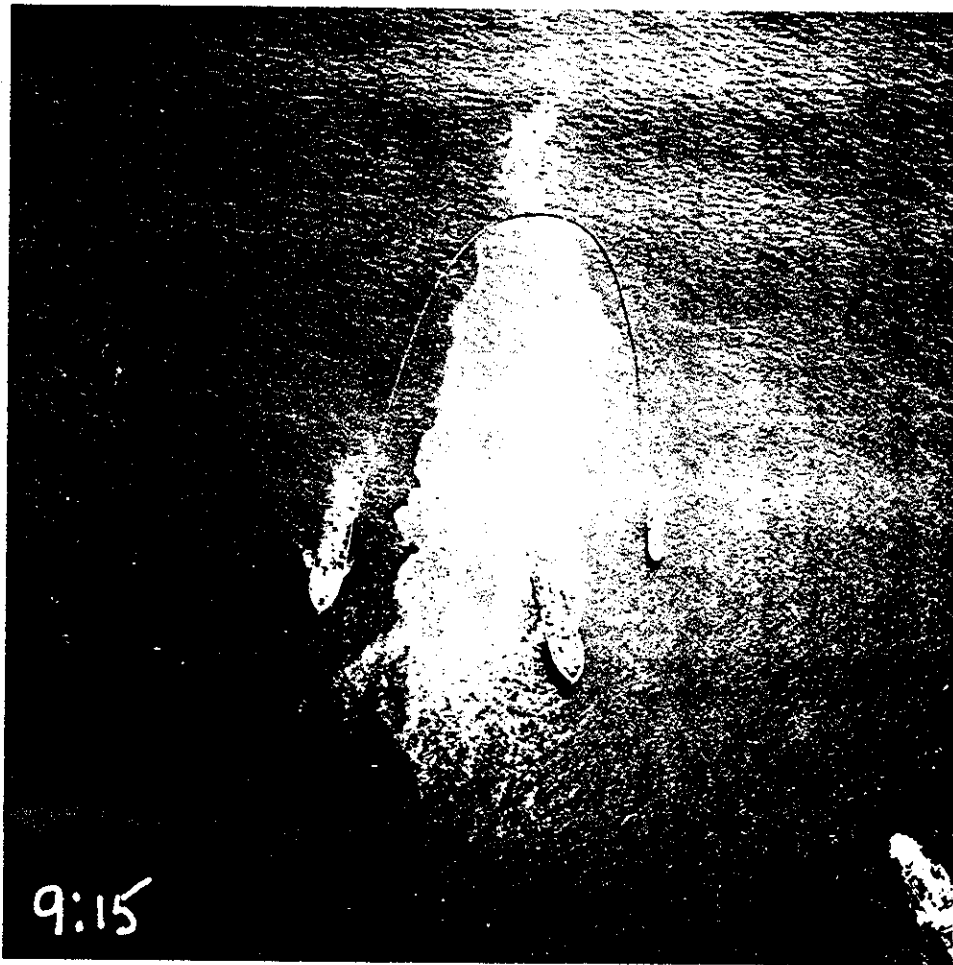


Figure 10 — Leakage of sheen past RO-BOOM; note very little oil against boom

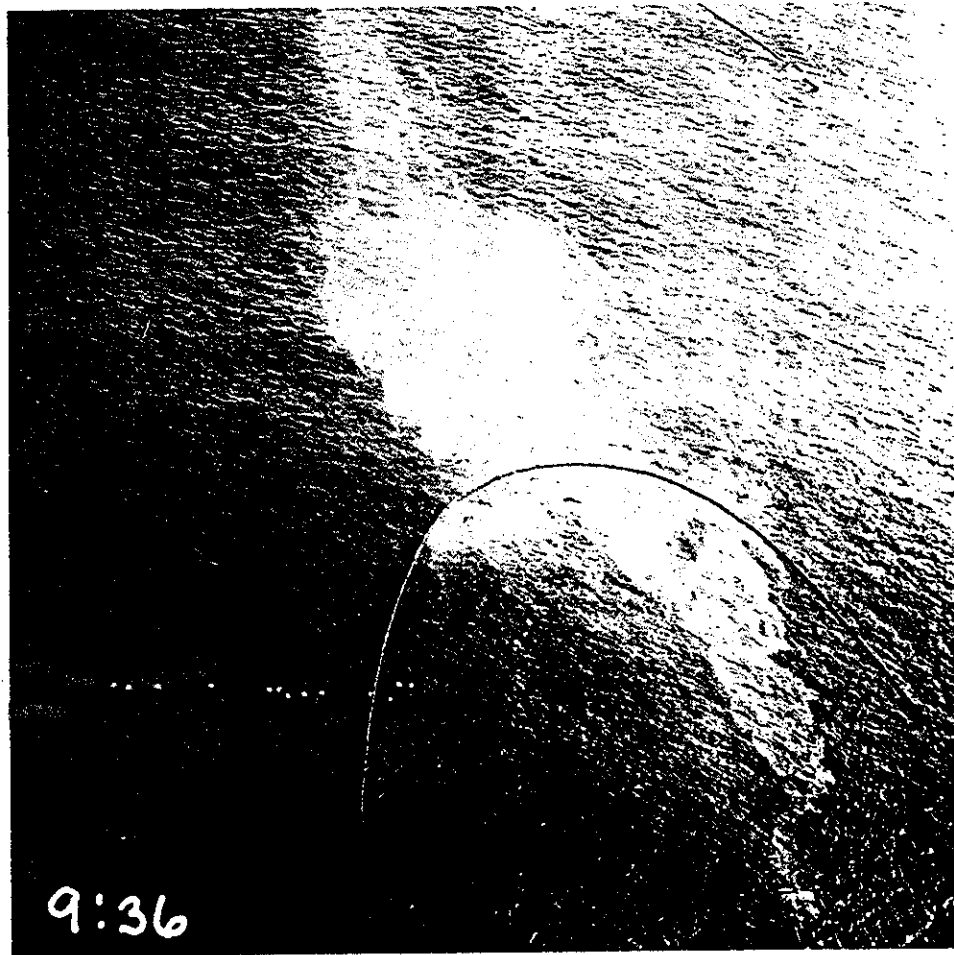


Figure 11 — Greater leakage of sheen past RO-BOOM; note change in width of sheen due to increase in volume of oil contained compared to Figure 18

that the slick thickness was reasonably constant. As noted previously no testing to first loss, by increasing speed, was conducted with the RO-BOOM though splashover losses were noted by personnel in a small boat near the end of the test.

Figure 12 shows a comparison of relative RO-BOOM/water velocity and oil leak rate during the skimmer trials. Relative water velocities were higher at this time than during the morning test since the tow vessels were now heading downwind and needed to move faster to maintain steerage. Visually estimated leak rates were slightly higher (1 to 2) than previous (0.5 to 1). The evening leak rate data could be grossly underestimated as surface vessels to windward of the skimming vessel reported considerable numbers of emulsion balls in the sheen emanating from the skimming operation (Figure 13). It is possible that some or even all of this emulsion may have been driven beneath the boom by the cooling water discharge from the skimming vessel when it impinged on the oil in the boom.

Vikoma Ocean Pack

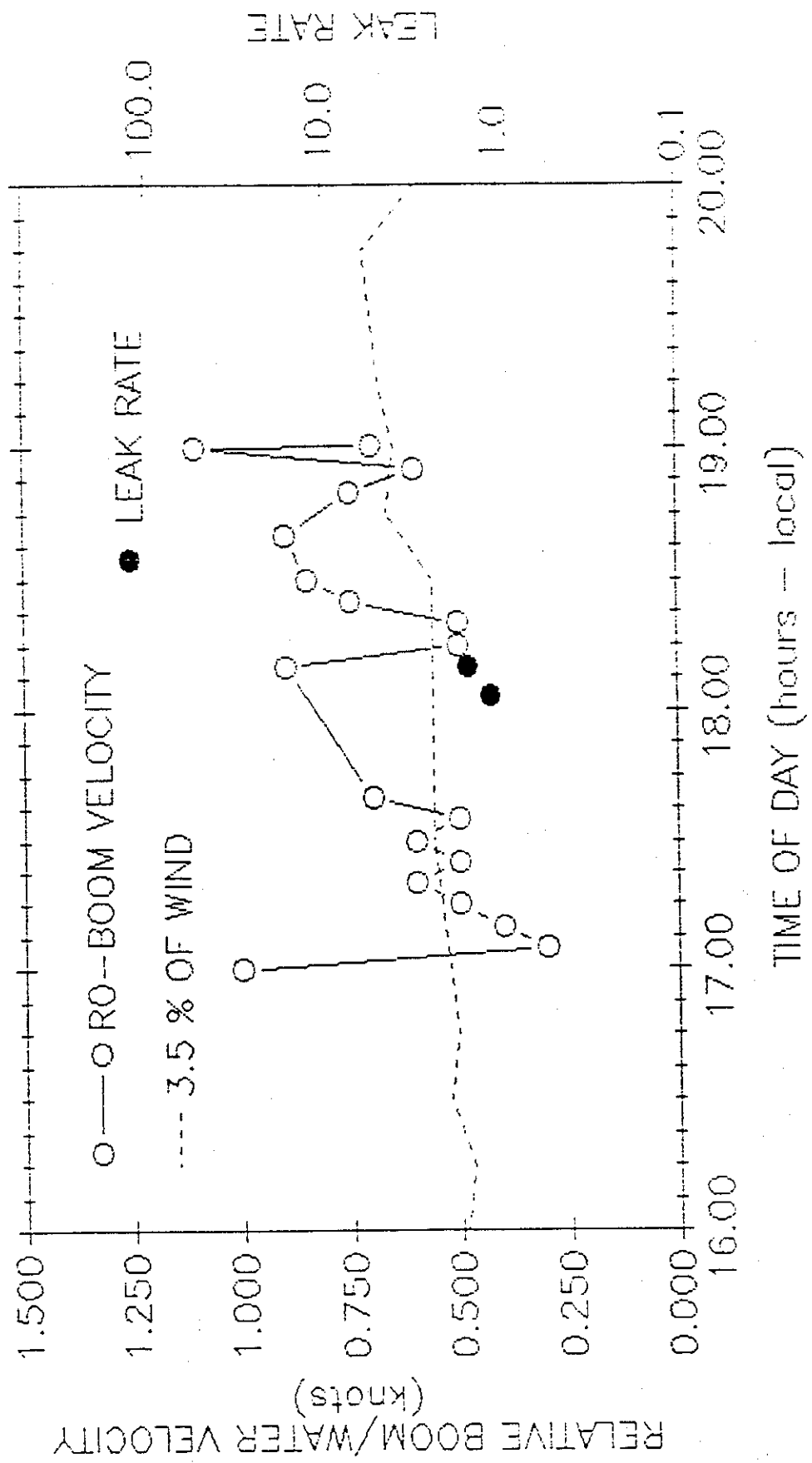
Figure 14 compares the leak rates and relative boom/water velocities for the period of time before, during and after the test of the Vikoma Ocean Pack. Wood chip drift time data for both tow vessels is available only for a 45 minute time period during the actual boom tests. Drift velocities from the tow vessel CCGS Grenfell are plotted as an indicator of relative boom/water velocity before and after the test however, as can be seen by comparing the Grenfell data with the calculated data from both vessels during the test period, there can be a considerable difference between the two. Prior to the test the Grenfell data is likely an underestimate of the actual velocity since during this period the other tow vessel was manoeuvring while the Grenfell maintained station. The roles reversed after the test and thus the Grenfell data for this period probably overestimates actual velocities.

Prior to the test, when the Vikoma boom contained only very small volumes of oil and velocities were low, the relative leak rate was on the order of 0.1 (Figure 15). After intercepting the oil released from the OHMSETT instrumented boom at about 1330 the boom contained about 300 m² of oil with a reported visually estimated thickness of 2 to 5 cm translating to some 6 to 15 m³ of oil. At this time the relative leak rate was 1.0 (Figure 16) with a relative boom/water velocity of 0.25 m/s (0.5 knots).

The phenomenon of the Vikoma boom creating a small breaking wave at the juncture of the air and water chambers was observed. This likely causes some dispersion of oil beneath the boom but the rate would be very low. In booms full of oil this wave would likely be damped out. Previous tests with the Vikoma boom have reported a phenomenon where these waves prevent the slick from touching the boom; this was not observed in these trials. As the tow vessels manoeuvred the Vikoma Ocean Pack into a "J" configuration the relative velocity increased to in excess of 0.5 m/s (1 knot) and the relative leak rate increased dramatically to 200. Even this number may be conservative as visual estimates of the slick trailing the boom gave thicknesses of 3 to 4 mm or relative leak rates of 600 to 800. All the oil was lost from the boom pocket in a period of about 5 to 10 minutes. The cause of the oil loss was slick entrainment beneath the boom (Figure 17); little splashover and no boom sinking or wave topping was observed.

Subsequent to this the tow vessels repositioned heading downwind and recollected some thick oil; leak rate estimates are not available for this time period since it was impossible to distinguish oil emanating from the boom from the oil surrounding the area. During manoeuvring to reform a "J" at approximately 1430 for a second skimming attempt with the Vikoma boom, the relative boom water velocity exceeded oil containment limits and most of the oil was again lost. Following this second effort excessive strain was placed on the boom during manoeuvring causing

FIGURE 12
RO-BOOM LEAKAGE DURING SKIMMER TESTS



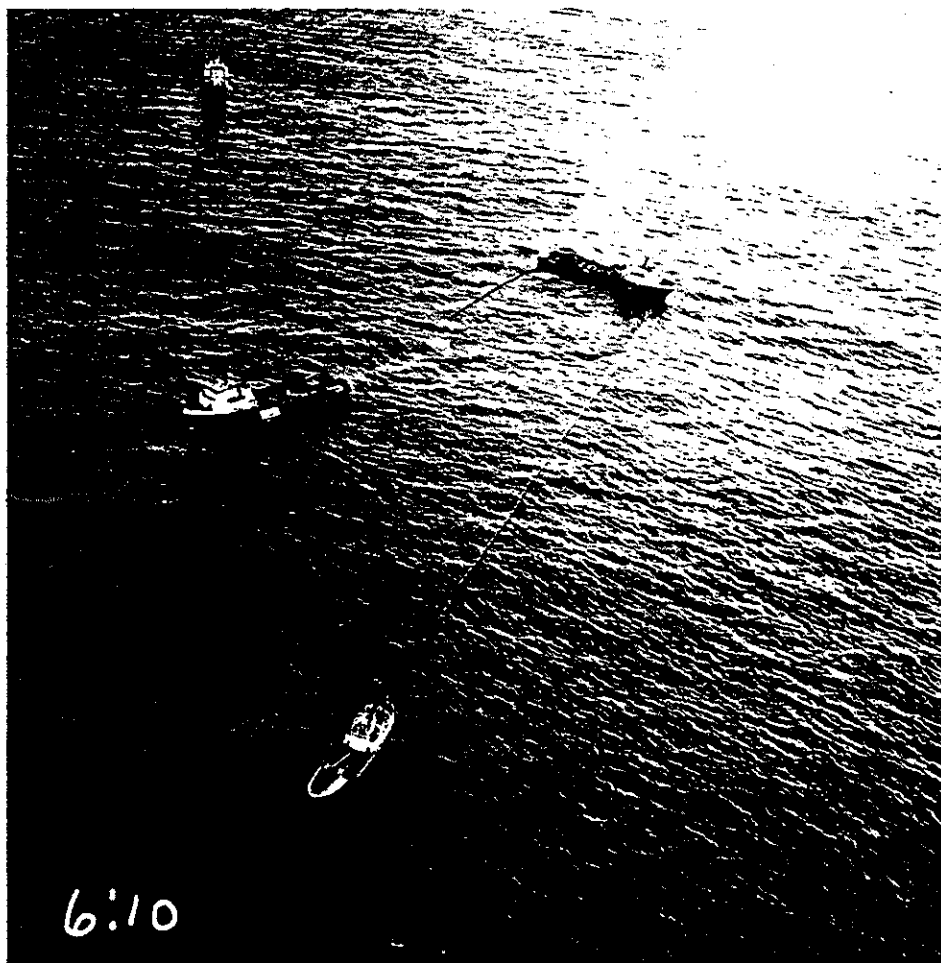
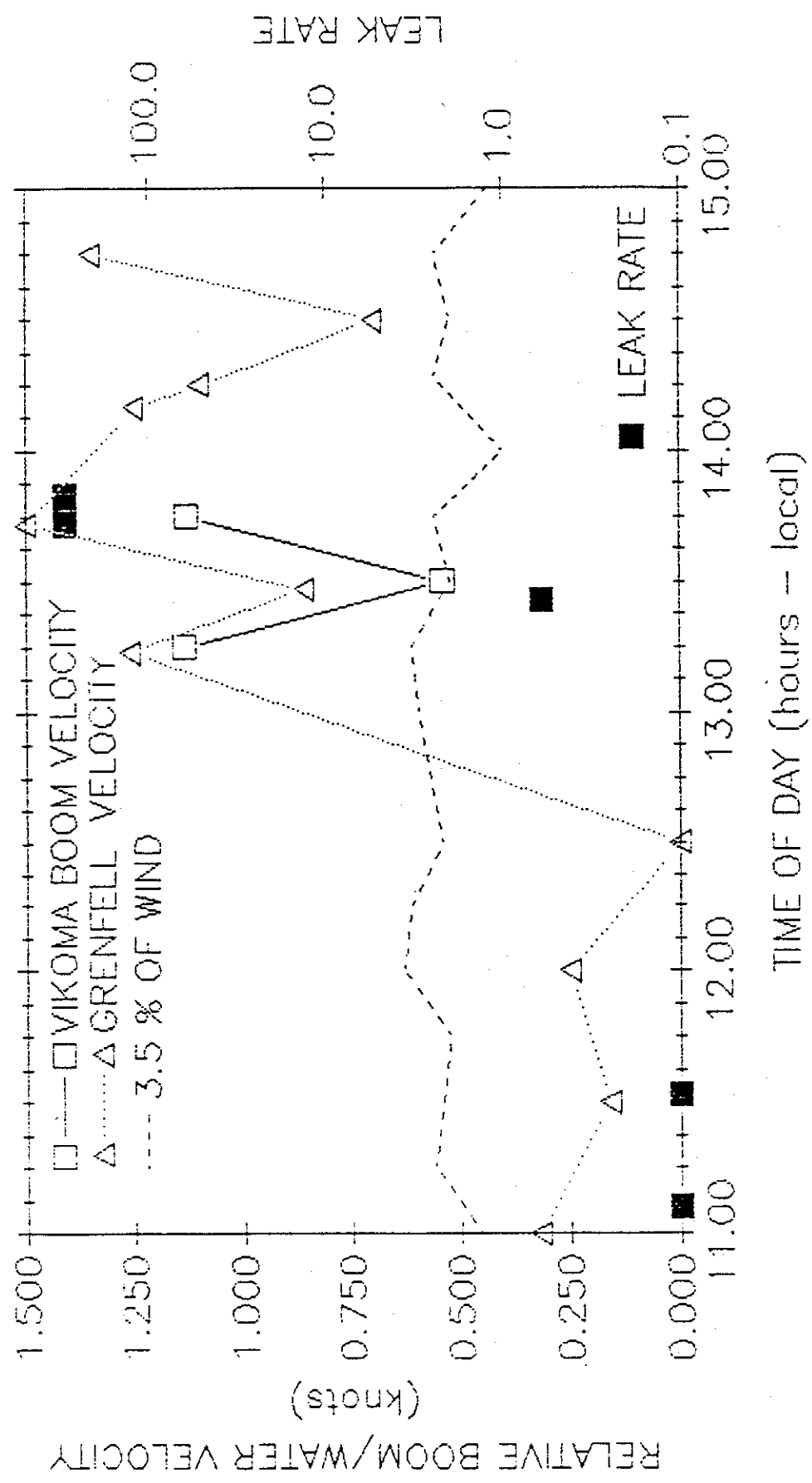


Figure 13 — Oil leakage from RO-BOOM during skimmer trials (compare sheen width to Figures 10 and 11)

FIGURE 14
VIKOMA OCEAN PACK LEAKAGE



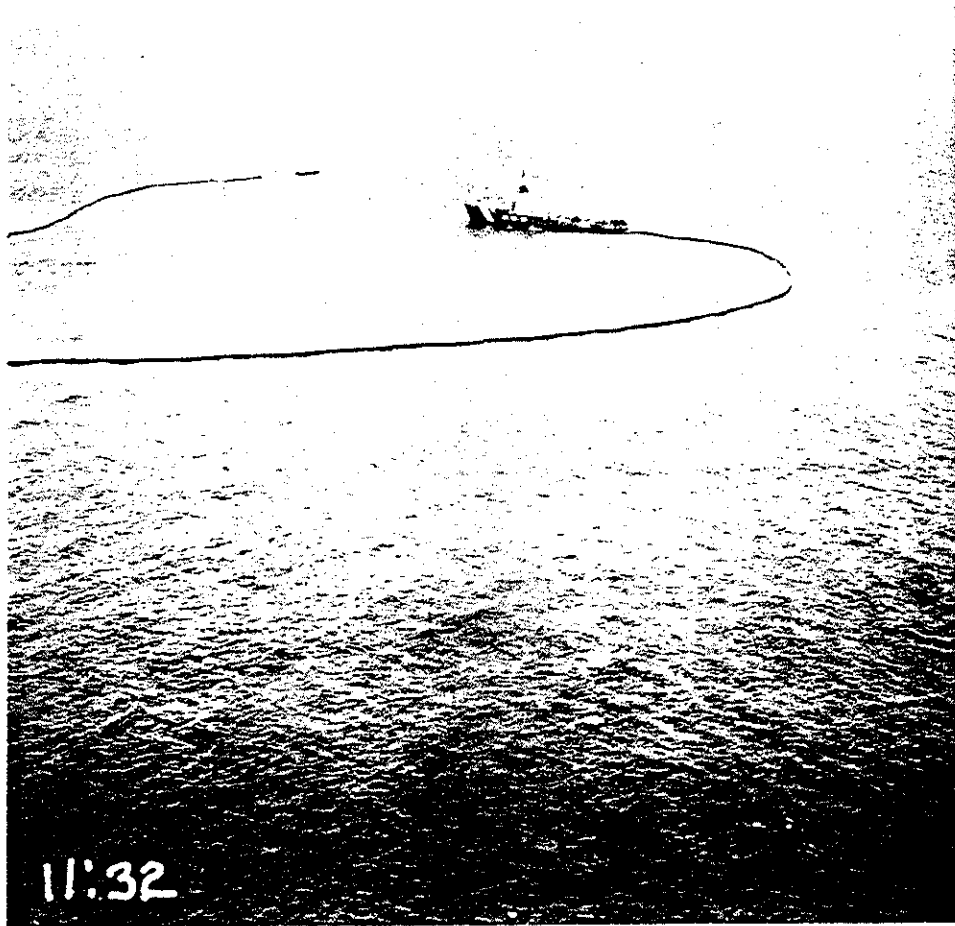


Figure 15 — Vikoma Ocean Pack leakage while containing very little thick oil

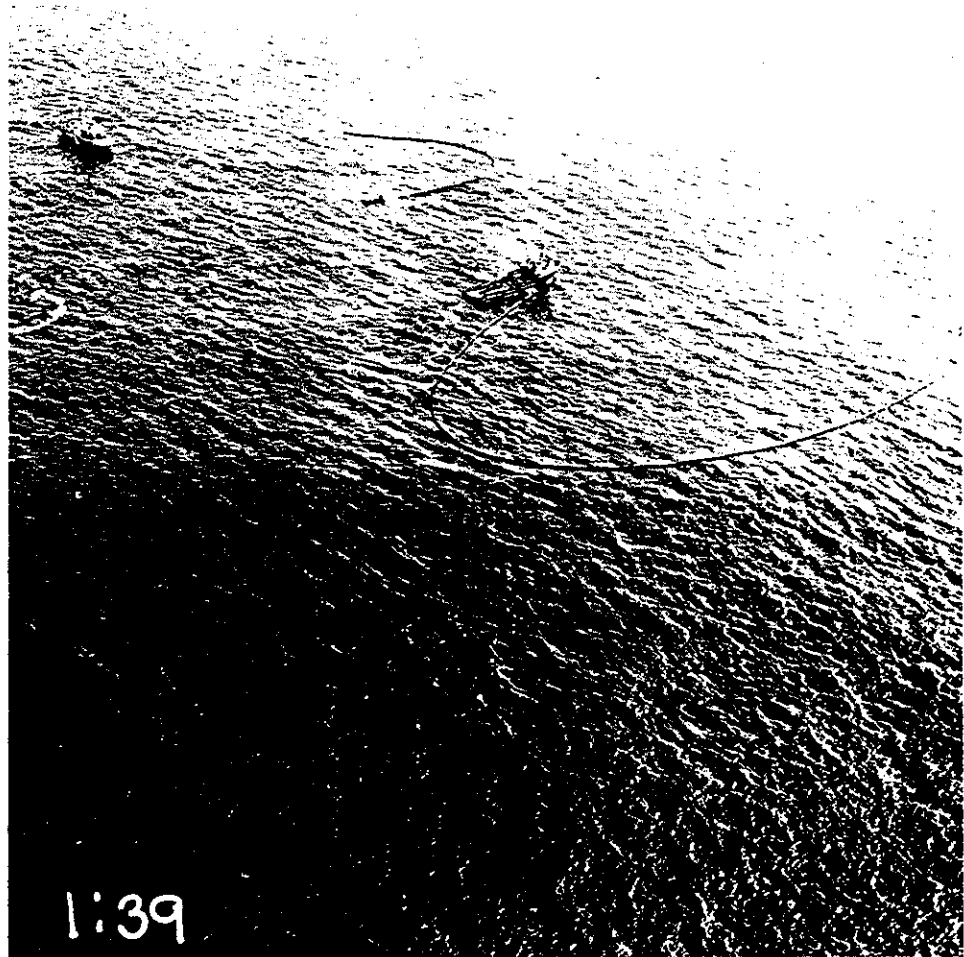


Figure 16 — Vikoma Ocean Pack leakage while containing thick oil; note area of thick oil.



Figure 17 — Significant leakage of oil from Vikoma Ocean Pack. Relative boom/water velocity in excess of 0.5 m/s (1 knot)

the boom to lift from the water for as much as 10 m between wave crests on several occasions.

Comparison Figure 18 compares the leak rate and relative boom/water velocity data for both the RO-BOOM and the Vikoma Ocean Pack. Based on the estimated leak rates both booms performed equally well while maintaining station into the wind. The high loss rate from the Vikoma Ocean Pack during manoeuvring into the wind is related solely to the fact that, under the wind conditions at the site, any manoeuvring upwind caused relative boom/water velocities to exceed containment limits ($0.5 \text{ m/s} = 1 \text{ knot}$). This is a factor independent of boom design. It is worth noting that the winds at the test site particularly during the afternoon and evening (15 to 20 knots), were near the maximum operating limits for any containment boom (20 knots) operating in a stationary upwind mode. Wind driven wave heights would also have continued to increase from the last observation of $1.3 \pm 0.2 \text{ m}$ at 1900 hrs to approach the upper limits for boom containment (1.5 to 2 m) by the end of the trials at 2036 hrs.

In general, the RO-BOOM seems slightly more prone to splashover in the upwind mode while the Vikoma boom seems slightly more susceptible to wave-induced dispersion losses.

Both booms were judged acceptable for use offshore; the limiting wind and sea state for their use in containing slicks in a stationary mode, oriented into the wind would be only slightly higher than the conditions encountered during the trials. The booms could be used in still higher wind/sea conditions but only in a downwind mode (as was the case in the late afternoon and evening during the trials). This approach to extending the limitations of offshore containment and recovery (i.e., operating downwind) could be effective when attempting to chase individual slicks but would not prove useful when operating at the site of a stationary oil spill source, such as a blowout, where the objective is to capture the slick as near to the source as possible (by definition by operating into the seas).

Skimmer Performance

Due to the time required to collect sufficient oil for the skimming tests, deteriorating weather conditions, darkness, the addition of Elastol to the oil between skimmer tests, and mechanical difficulties with the Heavy Oil Skimmer, it was impossible to conduct thorough tests of the skimmers that would permit complete evaluation of their effectiveness on spills of waxy crude oils. Regardless, valuable information was collected on the general performance of the skimmers.

Once sufficient emulsion had been contained within the pocket of the RO-BOOM (about 300 m^2 , with an estimated thickness of 10 cm, or 30 m^3 , 7900 gal) the skimmer tests commenced. The results for each skimmer are discussed separately.

Framo ACW-400

Recovery Rates Figure 19 shows the flowrates measured for the fluid recovered by the Framo ACW-400 skimmer. There is an obvious discrepancy between the results from the Venturi meter readings and the results from the tank soundings. Examination of the raw Venturi data (McKowan and Borst 1987) shows that in many of the 3-second data sampling periods, the maximum recorded value is the upper limit of the equipment, thus the 3 second recorded averages, and the 1 minute averages calculated for Figure 19 are underestimates of actual flow conditions. For this reason

FIGURE 18
BOOM LEAKAGE RATES

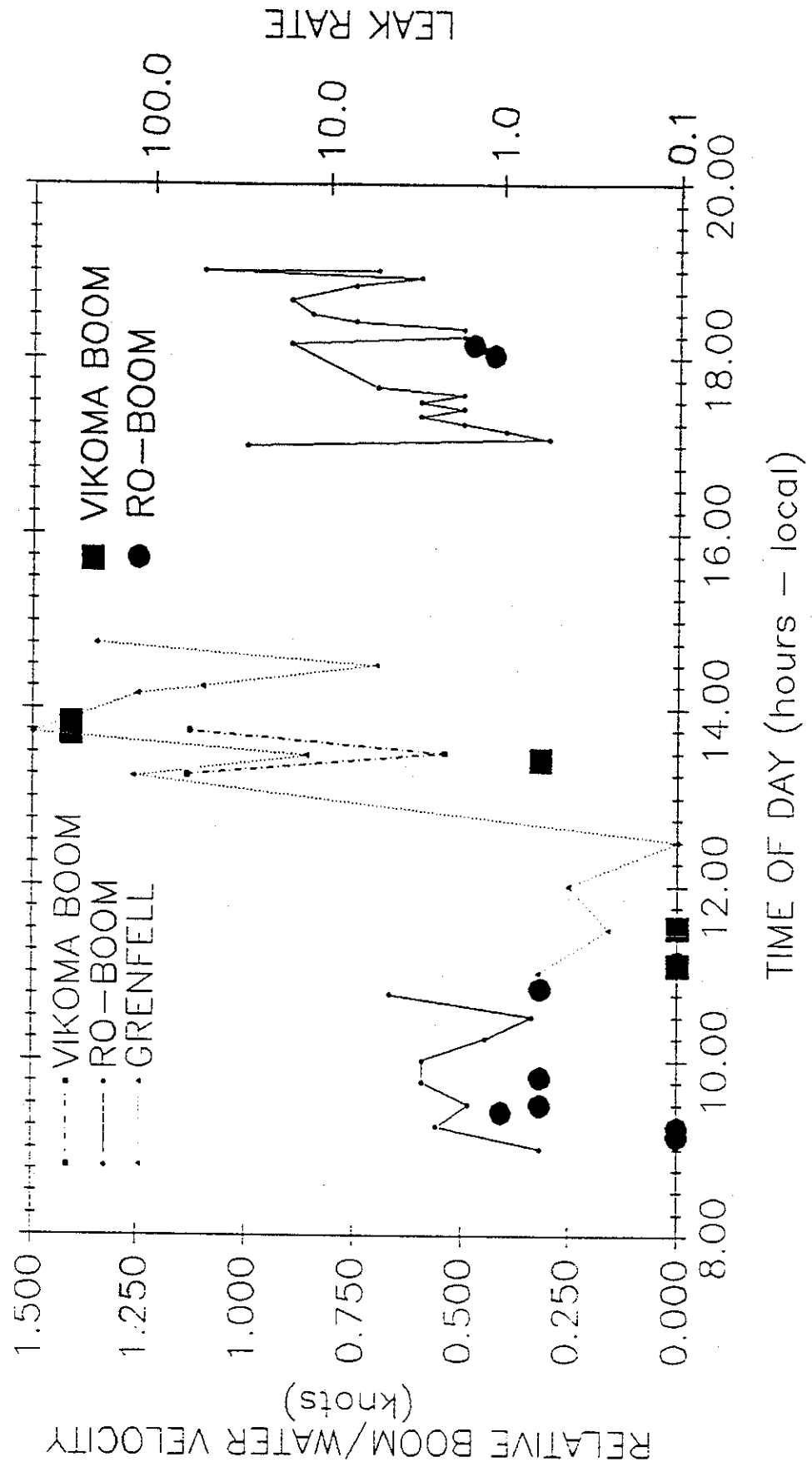
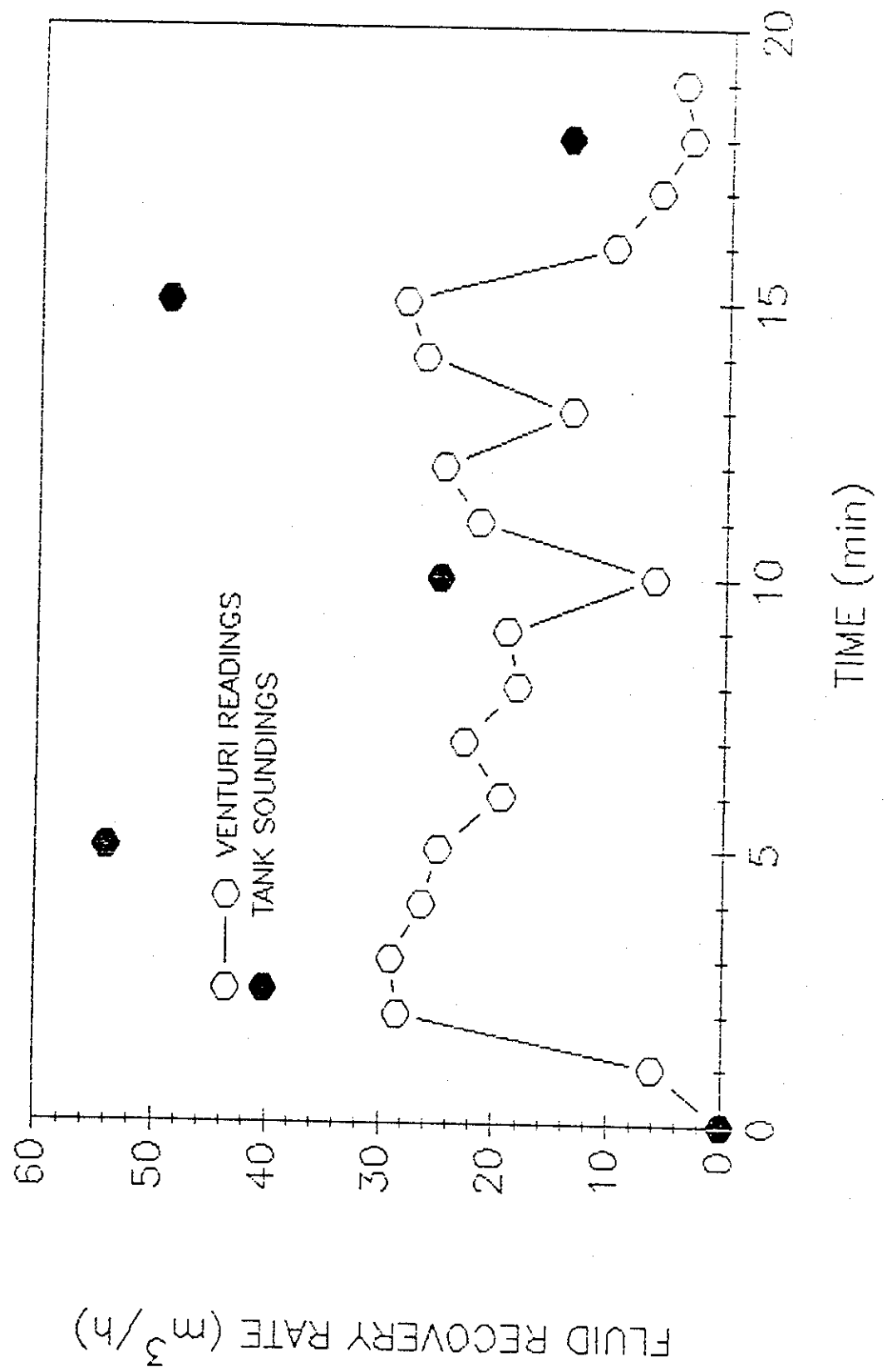


FIGURE 19
FRAMO ACW-400



the performance assessment of the Framo ACW-400 skimmer is based on tank sounding data only. Over the 23 minute test period the Framo recovered some 11.6 m^3 (3065 gal) of fluid at an average recovery rate of $39 \text{ m}^3/\text{hr}$ (172 gal/min). After accounting for 5 m^3 (1320 gal) of free water recovered and 2.5 m^3 (660 gal) of water in the emulsion recovered the oil recovery efficiency for the Framo ACW-400 was 35% ($14 \text{ m}^3/\text{hr} = 60 \text{ gal/min}$). The maximum fluid recovery rate recorded was $54 \text{ m}^3/\text{hr}$ (240 gal/min).

General For the first few minutes of its test the Framo ACW-400 was incorrectly positioned at the outer edge of the oil and was collecting primarily water. During the last few minutes of its test, Elastol was added to the slick; this had no measurable or observable effect on its performance probably because the Elastol had not had sufficient time to act on the oil. During its period of operation it was noted that waves frequently flooded the collection well of the Framo ACW-400 skimming head resulting in the recovery of large volumes of water. Based on observations of the other two skimmers tested in a free-floating mode, it is possible that the oil recovery efficiency of the Framo ACW-400 could have been greatly improved by operation in a free-floating mode rather than attached to the hydraulic arm. Observations of the action of the skimmer head suggest that the motion-compensation in the Framo ACW-400 hydraulic arm can adequately deal with the pitch and roll of the skimming vessel but cannot compensate for shorter period wave action.

Visual observation of the discs during the skimmer test indicated that the waxy oil was not adhering well; unfortunately the Framo ACW-400 was not redeployed and tested after the Elastol had acted on the oil and no comparisons can be made.

GT-185

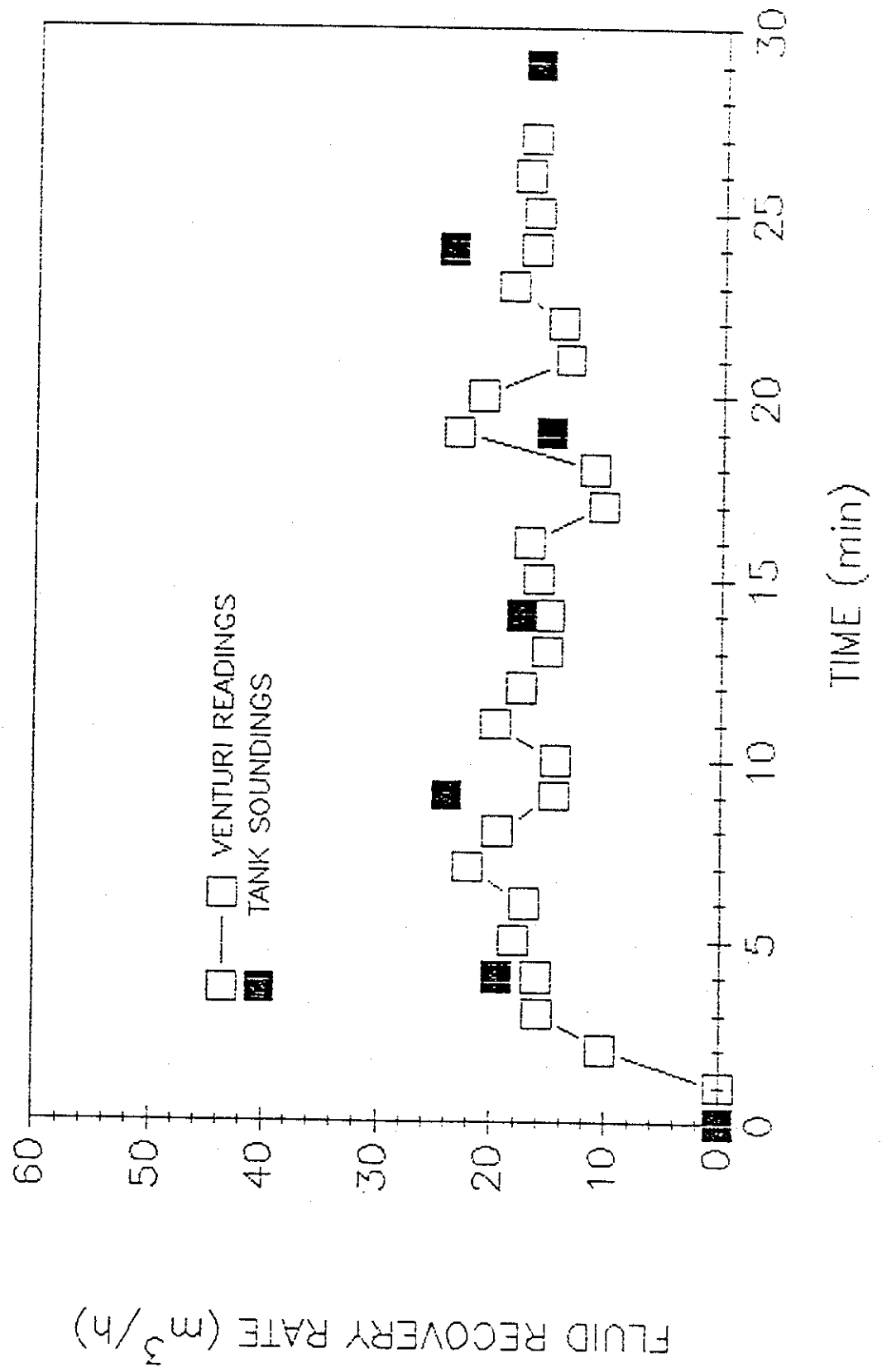
Recovery Rates Figure 20 shows the fluid recovery rates measured with the Venturi meter and tank soundings for the GT-185 skimmer during its test. In this case, since the fluid recovery rates were lower than during the Framo ACW-400 test, the two sets of data correspond well. Over the 29 minute test period the GT-185 collected a total of 9.4 m^3 (2480 gal) of fluid at an average recovery rate of $19 \text{ m}^3/\text{hr}$ (85 gal/min). After accounting for 5 m^3 (1320 gal) of water in the emulsion recovered (no free water was measured), the oil recovery efficiency was 46% ($9 \text{ m}^3/\text{hr} = 40 \text{ gal/min}$).

The maximum fluid recovery rate measured (over a 5 minute period) was $24 \text{ m}^3/\text{hr}$ (105 gal/min).

General Since the test of the GT-185 skimmer took place subsequent to the addition of Elastol to the slick, no evaluation of the effectiveness of this skimmer for the recovery of waxy crude oils can be made. In general the skimmer operated without incident during its test and, due to its free-floating mode, followed the waves very well, as evidenced by the absence of free water in the recovered product. On one occasion the skimmer did snag on the boom when the skimming vessel drifted slightly off station, but the skimmer was undamaged.

The Elastol rendered the oil viscous resulting in high pressure drops in the skimmer discharge and perhaps reducing the performance of this device.

FIGURE 20
GT-185



Heavy Oil Skimmer

The heavy oil skimmer was deployed four times: once into the collapsed "J" formed by the Vikoma Boom and three times during the skimmer tests utilizing the RO-BOOM. Only during the last deployment, in emulsion to which Elastol had been added, was recovery rate data recorded. Unfortunately, this last deployment was cut short when the discharge hose from the skimmer burst.

Recovery Rates Figure 21 shows the Venturi data that was collected prior to the failure of the discharge hose, and the termination of the trials due to darkness and deteriorating weather.

No tank sounding data is available since the discharge hose burst before the recovered fluid filled the hose to the tank. Over the five minute test period the skimmer recovered an average $11 \text{ m}^3/\text{hr}$ (50 gal/min) of fluid. The maximum fluid recovery rate was $20 \text{ m}^3/\text{hr}$ (90 gal/min). It should be noted that this recovery rate was obtained with only one drum of the Heavy Oil Skimmer fully operational; the absorption fabric on the other had been damaged in the previous deployment and only 30–40% of this drum was covered. Based on one sample of unknown origin the oil recovery factor was 35% ($4 \text{ m}^3/\text{hr} = 20 \text{ gal/min}$). No information on the amount of free water vs. water contained in the emulsion is available for this sample.

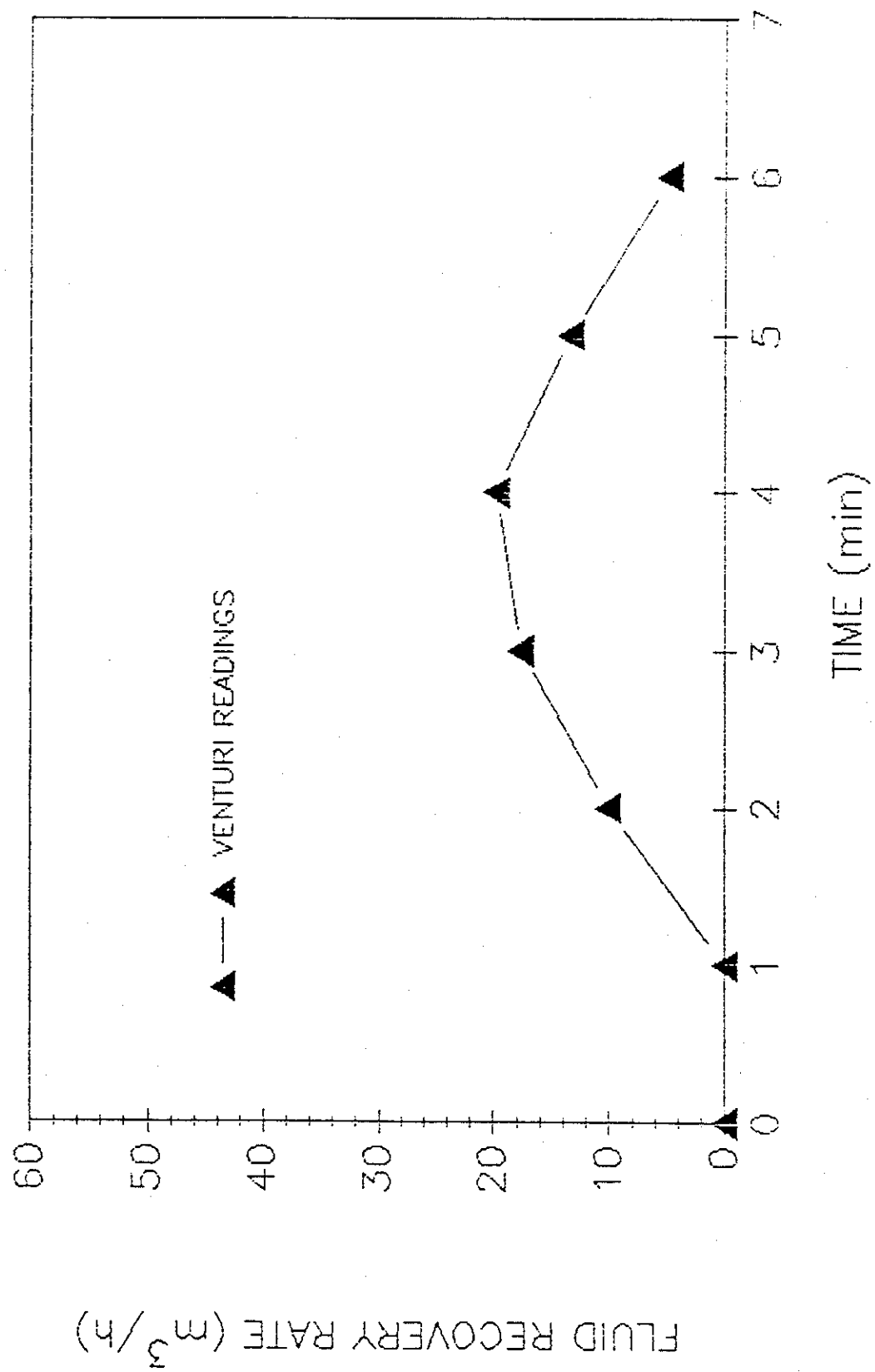
During a previous deployment in the slick prior to Elastol addition, it was observed that very little oil was adhering to the drums of the Heavy Oil Skimmer; no recovery was measured (Figure 35). In comparison, operation of the drums in oil to which Elastol had been added resulted in a layer of oil 1 cm (0.4 inch) or thicker adhering to the drums. One observer noted that the skimmer operated as well or better in the reverse rotation mode (pushing the oil down beneath the drums and up onto the scrapers) as it did in the normal rotation mode (pulling oil up over the top of the drums and down onto the scrapers).

General For the first two deployments of the Heavy Oil Skimmer it was attached to the Framo unit hydraulic arm by means of a universal joint. This caused excessive pitch and roll of the skimmer, causing complete submergence of one roller on one occasion. For the third deployment, the universal joint was replaced by a short length (0.6 m) of rope. This allowed the skimmer to operate in a free-floating mode and follow the waves much better. Unfortunately, the short rope length required that the hydraulic arm remain in close proximity to the skimmer and, during one roll of the skimming vessel the hydraulic arm hit one drum and tore the fabric. For the last deployment the heavy oil skimmer was attached to the hydraulic arm by a much longer chain.

During the first deployment of the Heavy Oil Skimmer (into the pocket of the Vikoma boom) the snagging of the skimmer by the boom caused the failure of a hydraulic hose; this was easily repaired. The third deployment of the Heavy Oil Skimmer was unsuccessful because a bolt had fallen into the pump intake; this was quickly rectified.

Overall, the tests of the Heavy Oil Skimmer were unsatisfactory since insufficient data was collected to evaluate its performance in recovering waxy oil. Further testing is required. In general and based on visual observations, the skimmer seemed to work better in the oil with Elastol added (the skimmer was specifically designed to recover viscous oils such as Bunker C) and followed the waves much better when operated in the free-floating mode as opposed to hard-mounting to the Framo hydraulic arm.

FIGURE 21
HEAVY OIL SKIMMER



Comparison

Although it is impossible to draw quantitative conclusions from a comparison of the skimmers tested since the Framo ACW-400 was tested prior to Elastol being added to the slick, the GT-185 was tested after and the Heavy Oil Skimmer was operating with one damaged drum during its final test, a presentation of the data may prove useful for future studies.

Table 2 and Figure 22 compare the overall average performance measured for the three skimmers. The Framo ACW-400 achieved the highest recovery rate ($39 \text{ m}^3/\text{hr} = 170 \text{ gal/min}$) but much of this was free water. Discounting this, the Framo recovered $22 \text{ m}^3/\text{hr}$ (95 gal/min) of emulsion or an equivalent $14 \text{ m}^3/\text{hr}$ (60 gal/min) of oil. This, of all the tests, is the only one that represents the skimmers ability to recover waxy crude oil. Had the skimmer followed the waves better and been positioned in the thick portion of the oil for the entire test it is likely that the measured oil recovery efficiency (35%) would have been higher, but not dramatically so. The poor adherence of waxy oils and their emulsions to the oleophilic discs of this skimmer type is apparent in the relatively low emulsion and oil recovery rates (previous tests with non-waxy oils have yielded recovery rates in the 50 to $100 \text{ m}^3/\text{hr}$ range). Most of the oil recovered was as a result of the oil slopping over into the sump i.e., the skimmer was operating as a weir device.

In comparison, the GT-185 with a fluid (and emulsion, since no free water was collected) recovery rate of $19 \text{ m}^3/\text{hr}$ (85 gal/min) and an oil recovery efficiency of 46% seemed to be operating near capacity. This was evident from the occasional flooding of the collection well. It is possible that the performance of this skimmer was reduced by the addition of Elastol to the slick; the increased viscosity of the emulsion would reduce both flowrates over the weir lip and pumping rates.

The measured recovery rate of the Heavy Oil Skimmer ($11 \text{ m}^3/\text{hr} = 50 \text{ gal/min}$) is likely an underestimate for the performance of the skimmer in oil with Elastol added for two reasons: first one drum of the skimmer had been damaged resulting in the loss of 60 to 70% of the oleophilic fabric on its surface and second, it is likely that debris found blocking the Venturi throat reduced the pump discharge rate (the resulting backpressure seems the most likely cause of the subsequent failure of the discharge hose) and may have affected differential pressure readings. It is unclear whether this latter factor would result in under- or overestimates of flowrate.

Based on a visual comparison of the thickness of emulsion adhering to the Heavy Oil Skimmer drums before and after the addition of Elastol to the slick it is apparent that the Elastol dramatically improved the performance of this skimmer with waxy oil. This is not surprising since the skimmer was designed to recover heavy, viscous oil slicks such as those resulting from spills of Bunker C.

In summary, due to the non-sticky nature of the waxy crude oil used for these tests, the skimmers depending on an oleophilic surface as the collection principle fared poorly. Those utilizing a weir proved more suited to the task. The addition of Elastol to the oil improved the oil's adhesion to the Heavy Oil Skimmer dramatically, but likely detracted from the performance of the weir-type GT-185 skimmer by increasing the oils viscosity and thus flow over the weir and through discharge hoses. This latter observation is important since it is known that some oils discovered on the Grand Banks are much waxier than the test crude and thus will likely be present as very viscous semi-solid mats or droplets rather than the comparatively fluid oil used for these tests (S.L. Ross and DMER 1987). Weir skimmers would likely perform less effectively in the more waxy oils, recovering less oil and more water (S.L. Ross and Hatfield 1986).

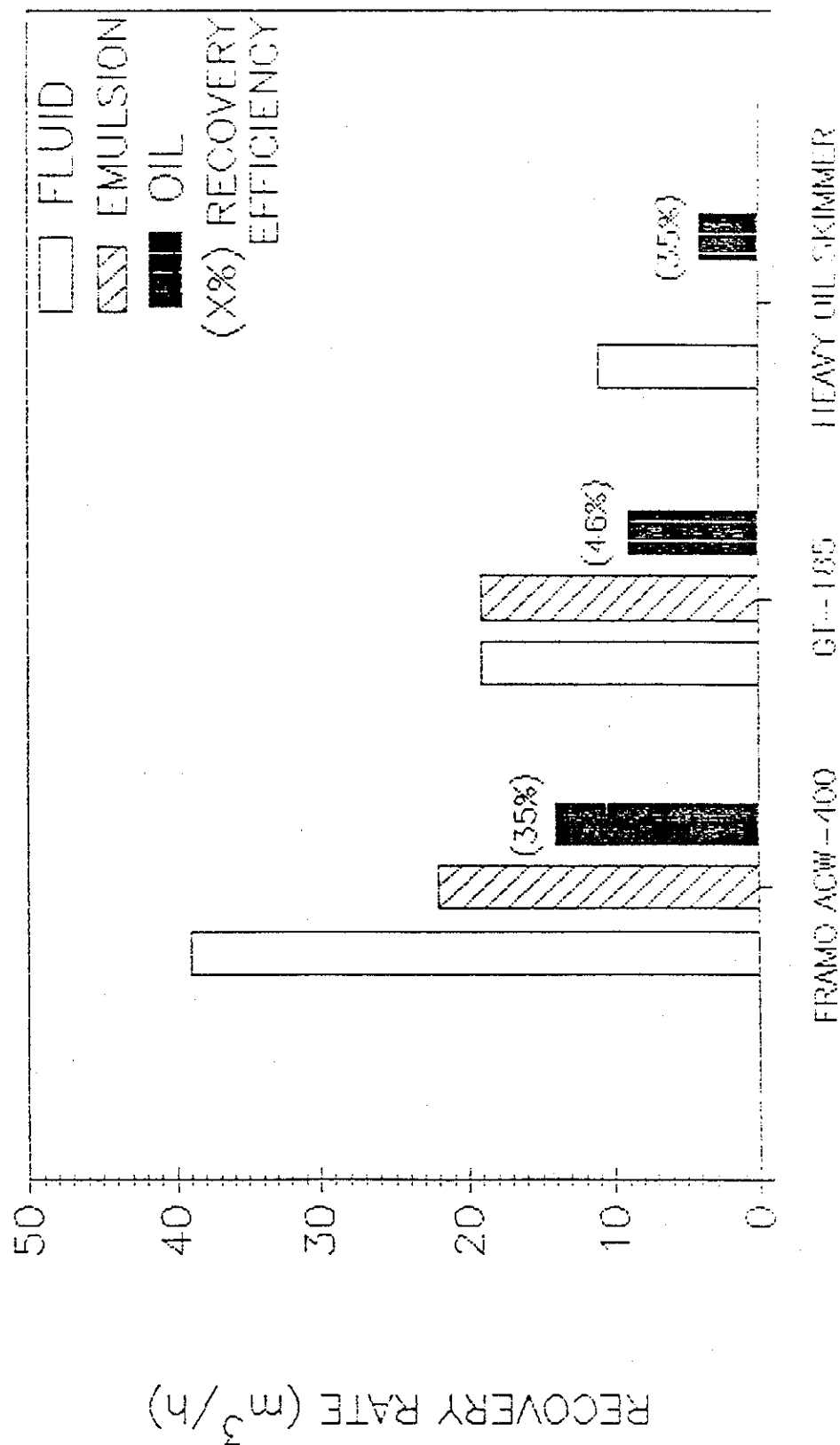
TABLE 2
OVERALL SKIMMER PERFORMANCE

SKIMMER	VOLUMES RECOVERED			RECOVERY RATE		EFFICIENCY (vol %)
	FLUID (m ³) (U.S. gal)	FREE WATER (m ³ /vol %) (U.S. gal)	EMULSIFIED WATER (m ³ /vol %) (U.S. gal)	OIL (m ³) (U.S. gal)	FLUID (m ³ /hr) (U.S. gal/min)	OIL (m ³ /hr) (U.S. gal/min)
FRAMO ACW-400	11.6 (306.5)	5.0/43 (1320)	2.5/38 (660)	4.1 (1085)	39 (170)	14 (60)
GT-185	9.4 (248.5)	0/0	5.0/54	4.4 (1160)	19 (85)	9 (40)
HEAVY* OIL SKIMMER	0	0	0/65*	0	11* (50)	4* (20)

* based on analysis of 6 minutes of venturi data and one oil sample only

FIGURE 22

COMPARISON OF RECOVERY RATES



CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Due to delays, deteriorating weather conditions and the addition of Elastol to the slick between skimmer tests (in order to improve recovery rates), it was not possible to draw quantitative conclusions regarding the capability of the skimmers to recover waxy crude oil spills in seas representative of Grand Banks conditions. The Framo ACW-400 skimmer (the only one successfully tested prior to Elastol addition) had an average fluid recovery rate of $39 \text{ m}^3/\text{hr}$ (170 gal/min) with an oil recovery efficiency of 35%. The GT-185 skimmer recovered Elastol-treated emulsion at an average rate of $19 \text{ m}^3/\text{hr}$ (85 gal/min) with an oil recovery efficiency of 46%. The Heavy Oil Skimmer, during one 6 minute test, recovered Elastol-treated emulsion at an average rate of $11 \text{ m}^3/\text{hr}$ (50 gal/min) with an oil recovery efficiency of 35%. Operation of the Heavy Oil Skimmer in the slick prior to Elastol addition resulted in no measurable recovery. Qualitatively, the oleophilic - principle - skimmers were ineffective in the untreated waxy oil. Elastol addition improved the recovery rate of the Heavy Oil Skimmer but likely detracted from the performance of the GT-185.
2. Both the RO-BOOM and the Vikoma Ocean Pack are suited to the containment of waxy oil spills in seas, representative of Grand Banks conditions up to sea state 3-4 and at relative currents less than 0.5 m/s. The Vikoma Ocean Pack boom was deployed and recovered faster and more easily than the RO-BOOM. The RO-BOOM was prone to splash-over of oil at the junction between floatation chambers; the Vikoma boom was prone to oil losses through dispersion by small breaking waves created at the junction of the air and water chambers. Both booms were judged to be equal in terms of sea-keeping and oil retention capabilities.
3. The sea and weather conditions prevalent at the site (sea state 3-4; winds 15 to 20 knots) represent the upper limit of stationary containment operations oriented into the wind. By operating in a downwind mode to reduce relative boom/water velocities and skimming in the lee of a vessel, recovery operations were possible in seas of 1.5 m and winds in the 10 m/s (20 knot) range, equivalent to sea state 4-5.

Recommendations

1. Further testing of the skimmers with waxy, viscous oils is strongly recommended to determine their capabilities.
2. The use of Elastol, and its effects on recovery operations and the environment, should be investigated further.

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